Nuclear Science (NUSC)
CTY Course Syllabus

"*Unless we choose to decentralize and to use applied science, not as the end to which human beings are to be made the means, but as the means to producing a race of free individuals, we have only two alternatives to choose from: either a number of national, militarized totalitarianisms, having as their root the terror of the atomic bomb and as their consequence the destruction of civilization (or, if the warfare is limited, the perpetuation of militarism); or else one supra-national totalitarianism, called into existence by the social chaos resulting from rapid technological progress in general and the atomic revolution in particular, and developing, under the need for efficiency and stability, into the welfare-tyranny of Utopia."* Aldous Huxley (1932—10 years before the first self-sustaining nuclear chain reaction produced by scientists.)

Introduction

With the dramatic advent of the atomic bomb in the 1940s, nuclear phenomena have been a focal point of not only the physical sciences but also the humanities, medical sciences, engineering, and even the arts in the 20th and early 21st centuries. From a few simple observations about the natural world, encoded in the theory of quantum mechanics, scientists have created hugely powerful weapons, techniques to explore the fine structure of the human brain and body, methods for dating archaeological objects to incredible precision, nuclear engines for naval craft, nearly unlimited power supplies through reactors, and a host of other advances which have drastically altered the way we go about our daily lives and have the potential to continue to do so in the new century.

Yet, across the world, governments scramble to keep weapons programs in check, the number of trained nuclear engineers is dwindling at a nearly uncontrollable pace, and despite the morass of known problems with carbon-based fuels, millions riot in protest of the construction of new nuclear power plants. Why? In this course we will learn not only the elegant and powerful science of nuclear physics, but will also seek to understand the use of nuclear technology in the context of modern life and politics.

Major Topics and Projects

Besides covering a large body of known material, I would like students to take the following idea out of this course: even though nuclear physics exists on a scale imperceptible to the human eye, it is a very tangible science with macroscopic implications, centered around a small number of reasonably simple principles. Thus, the course will be organized in as "ground-up" a manner as possible: beginning with the earliest theories of the nucleus and quantum world, developing tunneling, and spin, and working "up" to applications.

Meanwhile, one of the best visual (and quantitative) experiments in nuclear science is the bubble chamber, which allows us to literally see the ionization tracks of nuclear particles from either space or a table-top radiation generator; the apex of the course is for students to build their own bubble chambers by the end of the session. Finally, there will be one major and one or two minor projects during the session, which the students will present to each other.

Textbook

The Making of the Atomic Bomb, Richard Rhodes; plus my own notes and materials.

Course Outline

Day Number	**Topics and Activities**
1	Introductions, pre-test, safety and honor codes History of the atomic bomb: pre-WW2 politics and scientific status, including early models of the atom Intro to bubble chambers and their construction Schrödinger's cat and the nature of measurement Assignment of first small project: subatomic particle species
2	Quantum mechanics, part 1: Conservation laws and symmetries, quantum numbers Quantum states, discretized energies Particle nature of matter (photons vs. light waves) History: WW2 and the Manhattan Project
3	Quantum mechanics, part 2: Binding energies Energy-momentum conservation (“$E=mc^2$”) Transitions between states (particle decays, photon emission, lasers,...) The Hydrogen atom More general elements, structure of the periodic table Political climate of the bombs in Japan: early cold war history
4	Student presentations on particle species Heisenberg uncertainty (as well as energy-time uncertainty) Intro to fission, fusion reactions Nuclear weapons: difference between atomic and hydrogen bombs Fermi’s calculation of the power of the first reactor test pile (assignment of next small project: Fermi problems) *100 Suns* Teller vs. Oppenheimer vs. Einstein vs. ...
5	Isotopes Chemical reactions involving radioactive decays: alpha, beta, gamma decays... Interactions between matter and radiation, biological effects Positive vs. negative effects: irradiation of food, cancer treatments vs. nuclear fallout Discussion of the ethics of the bomb, historical aftermath Assignment of major project topics Check on bubble chamber progress: should have decent vacuum

Day Number	**Topics and Activities**
6	Nuclear physics of the sun: More details of fusion mechanics, fusion chains through iron Deaths of stars (dwarf types, black holes, cosmic rays, oh my) Measuring solar physics: neutrinos, neutrino oscillations, small intro to weak interactions The Ozone and protection from cosmic rays
7	Geiger counters and alternative detection methods Lab on detection of simple sources, detection around campus Tunneling: wavefunctions and potentials Gamov's theory of alpha decay: model of nucleus using effective potential, derivation of radiation rate, meaning of half life Beta and gamma decay Lab on carbon dating Intro to current energy crisis: statistics on non-nuclear power sources, reasons for ozone decay, oil and politics
8	Student presentations of Fermi problems Nuclear power, part 1: More on fission reactions Design of a nuclear power plant Power output, comparison to other energy sources Meltdowns and the story of Chernobyl; biking documentary
9	Project: nuclear submarine design Nuclear power, part 2: Byproducts of fission reactors, fuel cycles Refinement of waste into weapons materials Economics of nuclear power Cold fusion: how it could work, why it would be better, why it's hard, current status (cf. *The Saint*) Discussion of the ethics of nuclear power: should we build more plants? What do we do with the waste? What about "rogue states"?
10	Intro to spin Spin dynamics, differences with classical angular momentum NMR/MRI techniques Radiation treatments of cancer More classical imaging methods (eg. X-rays) Aldous Huxley's predictions on nuclear technology

Day Number	**Topics and Activities**
11	Final tune-up work on bubble chambers, tests of charges with magnets, etc. Fine structure of the nucleus: Experimental evidence for subnucleonic structure General structure of particle theories Salam-Weinberg-Glashow model of the electroweak interaction Quantum chromodynamics, confinement, open problems Brief intro to string theory as a model for quarks, other models
12	Student presentations on nuclear submarines Modern particle physics: Quark-gluon plasmas at RHIC Fermilab and CERN Hopes for CERN: Higgs, supersymmetry Discussion on the ethics of colliders: doomsday scenarios, government funding, etc.
13	Early universe cosmology: Intro to relativity and the Big Bang The early cooling universe, QCD vacuum, lepto- and baryo-genesis, formation of stars,... Cosmic microwave background Supernovae and extreme gamma ray bursts as tools of measurement Wheeler-DeWitt equation and the wavefunction of the universe
14	Research presentations
15	Final test/evaluations Wrap up